VISUAL GUIDANCE: SOLAR LED AVIATION LIGHTING AND SOLAR POWER SYSTEMS TECHNOLOGY SOLUTIONS

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BACKGROUND

The aviation landscape is growing at a rapid rate. The U.S. airport system already consists of more than 18,000 landing areas, 650 million square yards of pavement, as well as thousands of buildings and facilities that serve aircrafts, passengers and cargo. Serving over 600 million passengers yearly on scheduled flights and millions more in general aviation and other unscheduled service, it is critical that the U.S. airport system, and airport systems worldwide, adopt solutions that allow airports to support traffic and service growth [1].

Technology solutions currently in use worldwide have the potential to address many of the challenges facing airports today. Initiatives such as the Airports Technology Program, outlined in section 2.2 of the 2000 FAA National Aviation Research Plan, are committed to research and development efforts to meet challenges relating to airfield planning and design, visual guidance systems, environmental responsibilities, as well as many other pertinent issues [1].

A major goal for many airport systems is the reduction or elimination of aircraft accidents, as well as the reduction in the costs of developing and maintaining safe airports. One of the top three safety measures recommended by the National Transportation Safety Board (NTSB) is to prevent runway incursions [2]. The simplest ways to avoid incursions are to practice effective communications between pilots and controllers, and to improve pilot familiarity with airport taxiways and airstrips; however, these are not failsafe solutions. The NTSB recommends that airfields require visual guidance systems that give immediate warnings of probable collisions [2].

PREVENTION OF RUNWAY INCURSIONS USING SOLAR LED SOLUTIONS

Between 2001 and 2004, 1,395 runway incursions were recorded at 500 FAA-towered airports in the United States. This is an average of more than one incursion per day [3]. The NTSB is recommending that the FAA develop and implement ground movement safety systems that provide direct warning to flight crews.

In response, the FAA is installing ground-based systems, like Airport Surface Detection Equipment-X (ASDE-X), which warns controllers that an incursion is probable, who in turn must relay messages to flight crews. This lengthy process reduces the crews' time to react and take action to prevent or avoid an incursion [4].

Other scenarios include implementing Automatic Dependent Surveillance-Broadcast (ADS-B) to improve runway signage and markings. The FAA maintains that this is the ultimate solution; however deployment is not planned until 2014 [4].

In the interim, invested parties agree that something must be done to improve safety. However, many of the products currently available, which offer short-term solutions or an augment to safety do not meet FAA standards. Yet the question remains: when it comes to preventing runway incursions, is it not prudent to implement available safety precautions, than to take no action at all?

The US Department of Energy has documented solar energy as the most reliable energy source on earth, independent of power outages, grid failures, line loss, scheduled maintenance, cable replacement, cable failure, unexplained system failures and increasing energy costs [5, 6]. The FAA has been evaluating solar LED lighting since 2002, with a revision in 2004 to advisory circular AC 150 5345-50A, the specification for portable/emergency runway lights, stating that solar technologies are now acceptable.

While not yet completely sanctioned by the FAA, advancements in modern technology and the emergence of innovative solar products are making it possible for this alternative energy solution to support many aspects of airfield operations and increase safety measures cost-effectively. Whereas conventional hardwired electric airfield lighting systems were once the only option, today, solar-powered LED lighting systems are more reliable, more powerful, and already in use at many commercial and defense airports worldwide. The use of bright, reliable LEDs is making it possible for solar-powered lighting systems to compete with their hardwired counterparts.

Light Emitting Diodes (LEDs) have been in use for more than three decades, but they have only recently, around 2002, begun to gain the attention and respect of the lighting industry. The introduction of the LED for airport lighting visual aids represents the greatest potential change for lighted visual aids since their inception in the 1920s.

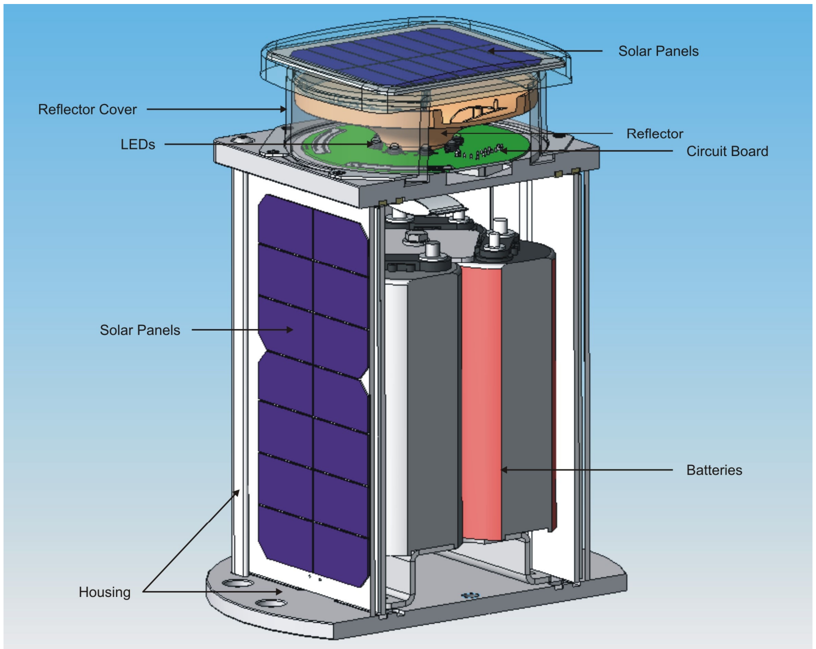

Figure 1. Illustrates the components of a typical solar-powered LED aviation light. The decisive factor that allows for compact, self contained, efficient and reliable operation and differentiates solar airport lighting products on the market today involves design and engineering, particularly with regards to energy management technologies.

Today, there are a wide variety of products currently available utilizing LED technologies and LEDs are competing successfully with conventional lighting technology. In fact, LEDs are rapidly replacing conventional incandescent and halogen systems. Proven to be very effective in applications such as airfield visual aids where brightness, visibility and durability are vital. LEDs are also particularly suitable for solar power due to their low voltage requirements.

SOLAR LED ELEVATED RUNWAY GUARD LIGHTS

Solar LED elevated runway guard Lights (ERGL) typically operate as a two system device with a self contained FAA approved metal housing supported by a 20 watt self contained solar power energy management system. There are several visual aid options available, including conventionally powered systems, retro-reflective markers, and solar LED ERGL systems.

Though the FAA has approved reflective markers for use as airfield visual aids, their passive reflective nature presents a barrier for the use of these visual aids in runway marking applications. There are several other operational restrictions associated with reflective markers. For example, illumination or lighting is dependant on the lights of the aircraft being placed squarely on the markers. This presents a safety risk when pilots are not on line with the runway or taxiway, or if the markers appear dim due to the quality of the landing lights or aircraft. In addition, while turning an aircraft, lights often fail to "illuminate" the markers, creating a dark and unsafe environment on the airfield. Testing with international aviation lighting authorities, international airports and Federal administrations has confirmed this phenomenon. Over time, the metallic surface of reflective markers wears down due to weather, chemicals, sand blast, and simply the lifecycle of the product. Performance gradually diminishes due to the degradation of the marker, limiting the effectives of the technology and lowering pilot safety for runway and taxiway operations.

As well, cold or adverse winter conditions can cause snow to stick to the surface of the markers, rendering them ineffective with little to no light. But perhaps the biggest disadvantage with reflective markers is that they do not self-illuminate at night. For this reason, retro reflective markers are not the desired solution for increasing airfield safety.

The alternative solution is to install a conventionally powered ERGL system, which incurs significant cost experienced in engineering design and consultation, electrical hardwiring, deconstruction of concrete, cable installation, airfield construction delays, disruption to airfield traffic, and construction crew costs. These costs are primarily associated with installing the system; however there are additional ongoing maintenance and energy costs with conventional hardwired systems. It is debatable whether or not either system adequately addresses the immediate needs for increasing airfield safety in order to reduce runway incursions. Solar LED ERGL systems offer an alternative solution that is reliable, operational and cost-effective.

While technically not approved for use by the FAA, Solar LED elevated runway guard lights (ERGL) offer an effective, reliable method of alerting pilots that they are approaching a runway intersection when a powered solution is not provided or available. Ideal for small to medium or remote airports as a temporary safety precaution or a supplement to existing visual guidance systems, solar LED ERGL systems can be implemented at a lower cost, and offer a 24-hour flashing amber beacon that operates continuously during low visibility and nighttime conditions. A properly operating ERGL system decreases the incidence of many aircraft collisions by providing pilots and vehicle operators clear, unambiguous information and directional guidance, which are key requirements of adequate visual guidance systems according to international research [1].

A solar LED ERGL does not require an external power supply as it operates using solar-charged batteries with the ability to adjust to meet varying brightness requirements of low, medium and high. A solar ERGL system is completely power-autonomous; therefore no wiring or trenching to connect to an external power supply is required. The solar panels, energy management system and battery system are housed in a solar engine. It can be mounted in virtually all solar environments depending on required candela outputs.

In addition to being robust and efficient, LEDs are low voltage devices that are naturally suited to solar power. This allows solar power to drive the LEDs within their optimum range for the greatest level of efficiency. LEDs allow for longer operation between battery charging and replacement.

Where the primary goal of an ERGL system is to be noticed in order to warn pilots and other airfield traffic of potential dangers, the brighter and more reliable the light source is, the more effective the overall system will be in fulfilling its purpose.

Currently being tested by the FAA, William J Hughes Technical Center, solar LED ERGL systems have the potential to provide permanent, fully-approved visual guidance solutions for medium sized airports. During testing, LED ERGL systems were observed to emit crisper, brighter, and more saturated light than an incandescent system. At brightness levels of 30 percent output, LED ERGL systems were visually observed to be equivalent to 100 percent outputs of incandescent systems. It was noted by the observers that the increased flash of the LED source provided a significantly better situational awareness of the location of the runway hold points. Overall, LED guard lights were regarded as “significantly more conspicuous” and “provided a significantly better situational awareness” [7].

In addition, solar LED ERGL systems can incorporate wireless control. This ability allows the control tower to activate the ERGL and other airfield lighting only when aircrafts are on the airfield. This not only allows the ERGL to run at much higher intensities, but also offers control for specialized operations.

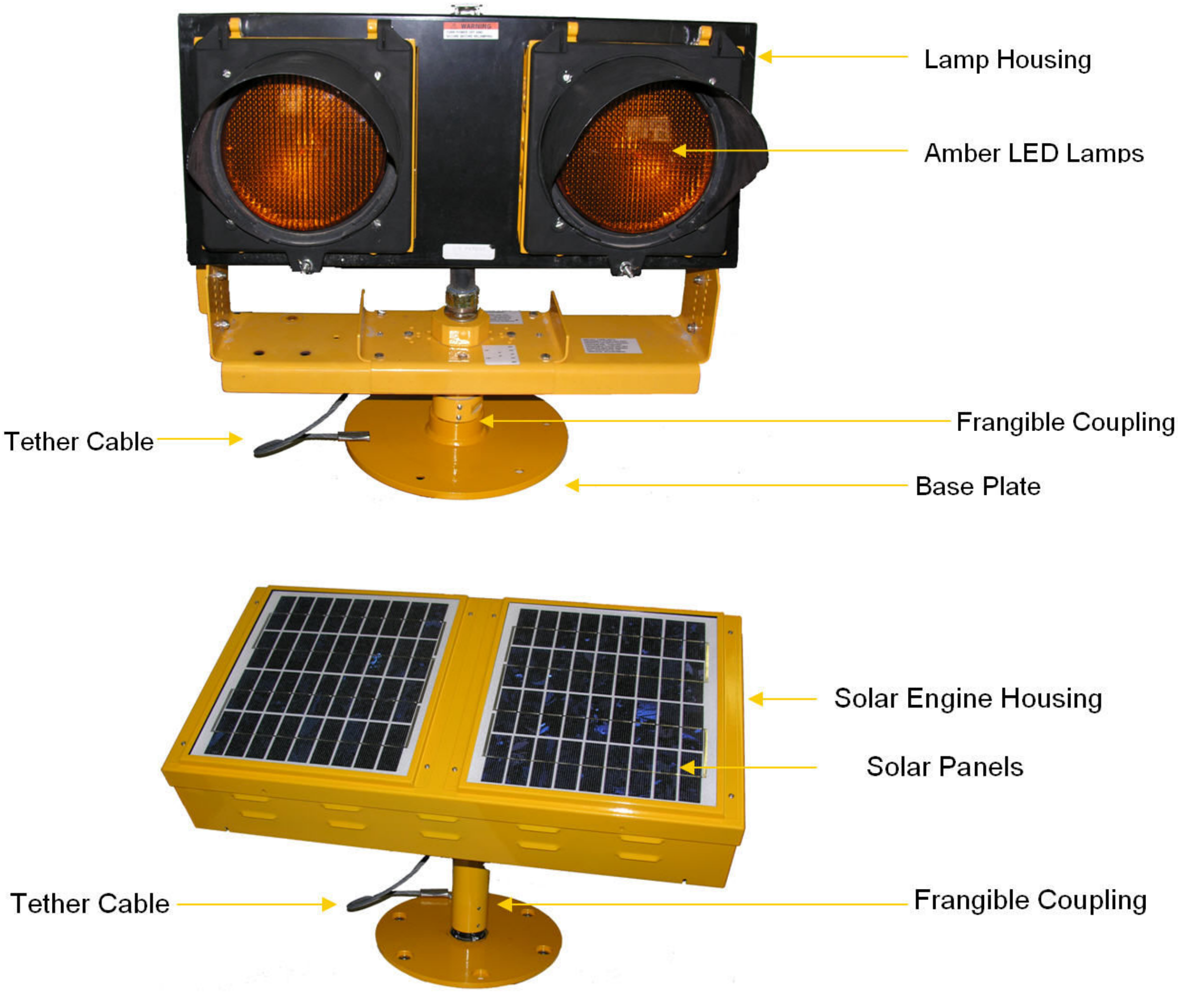

Figure 2. Components of a Solar LED ERGL System. The LED lights are enclosed in a separate housing that can be placed up to twenty (20) feet from the solar engine.

SOLAR ELEVATED RUNWAY GUARD LIGHTS WITH SUPPORTING ENERGY MANAGEMENT SYSTEMS (EMS)

It is critical for solar LED lighting products on the market today to incorporate power management capabilities in order to regulate the battery levels and power output. Using specialized electronics and software, power management technology can help optimize battery charge levels over the course of a day using the available solar power, responding to the environment in which it is installed. This can be extremely effective in maximizing product performance capabilities and reliability while extending the battery operating life. Using this type of power management technology some solar LED lighting products can reach an autonomy range of more than 200 hours on a single charge. Autonomy is the calculation of how long a unit will run during periods of no solar charging.

If using an advanced energy management system, a solar LED ERGL may last up to 20 days with no solar charging, and is designed to operate reliably with no scheduled maintenance for up to 5 years depending on environmental location and operation.

Power management systems use a two stage charging process:

1. In the initial stage of charging, the system creates a direct connection between the solar panel(s) and the batteries. This enables the system to achieve a maximum charge as early as possible during the day.

2. As soon as the batteries reach optimal levels (the float charging level), the system switches to a constant voltage charge mode. This mode ensures the batteries remain at their peak state until LED illumination is activated.

Power management systems also feature a low battery cutoff, which prevents deep cycling and battery damage in the event that the product operates for an extended period of time without receiving any daily solar charging.

Along with a battery system that maintains a 10-14 day operating capacity, products that incorporate Automatic Light Control (ALC) technology, will manage the product's light output levels in an effort to maintain optimal power storage levels with respect to installation location and any prevailing climatic conditions.

AUTOMATIC LIGHT CONTROL (ALC)

The single greatest inefficiency of outdoor solar-powered lighting products is that they must be optimized for the worst solar conditions they are likely to encounter. In practical terms, this means that each unit must be designed to operate reliably during the worst of the winter months, when the availability of ambient light for recharging is at its lowest. The result is that during summer months the unit is "overbuilt" and operating inefficiently, as it does not use much of the energy available for capture by its solar panels.

Similarly, unless each unit is customized individually, there is no means of adjusting the performance level of a unit to correlate with the solar energy available at the installation location. For example, a unit installed in Egypt, where there are six hours of sunlight on average every day, will have to be set to the same performance level as a unit installed in Patagonia, where there is only one hour of sunlight available on average. The unit in Egypt therefore operates very inefficiently, as most of its incoming solar energy is wasted.

Solar LED products that utilize automatic light control (ALC) software adjust their light output in response to prevailing solar conditions.

An ALC uses a control scheme to monitor the charge received by its batteries over the course of the day via the solar panel(s). Through a software algorithm the ALC recognizes any trend in its battery voltage levels so that it may develop an approximate understanding of its installation location and/or prevailing weather conditions. It then determines if solar conditions are suitable to maintain its current light output, or if it should dynamically adjust its output level to ensure its battery levels will remain optimal for continuous, reliable operation. Products incorporating this self-configuring capability operate reliably at nearly any location on earth.

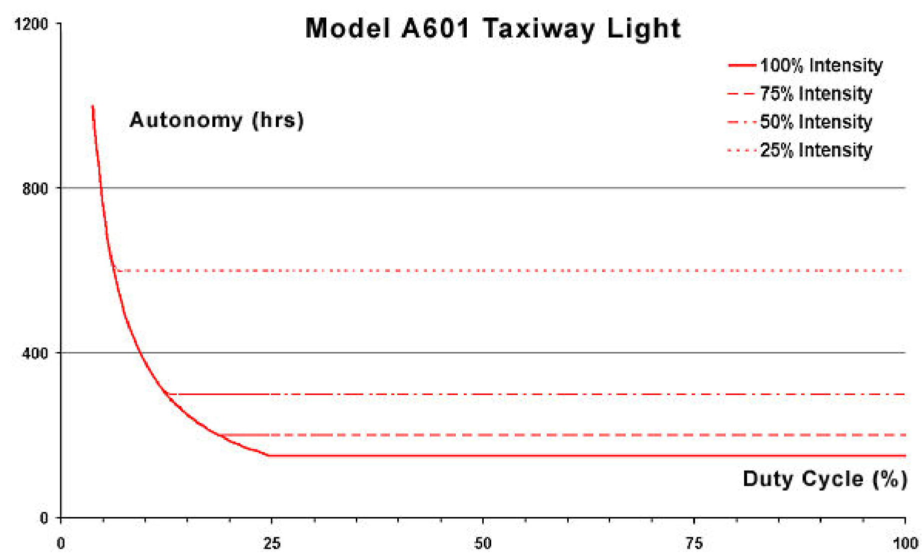

Figure 3. Autonomy Levels for a Solar LED Taxiway Light. A Solar LED ERGL system would have a similar level of autonomy; exact levels are still being tested.

Maximum Power Point Tracking (MPPT)

Maximum Power Point Tracking (MPPT) pertains to the balance of power, accounting for worst case solar conditions. The amount of power delivered by a solar panel can be maximized by matching the solar panel voltage to the voltage of the load. The load might be a battery being charged or an electrical device.

To ensure that a solar panel can charge a battery, the voltage of the panel must be higher than the voltage of the battery under all conditions. In low light, a solar panel produces lower voltage, but this must still be above the voltage of the battery.

As a result, the power delivered by the panel is not maximized. MPPT solves this by having the panel experience a load that allows it to deliver the maximum power, while providing the battery with the appropriate voltage to charge. This happens no matter what the solar conditions are. The result is an increase in power delivery of up to 30%.

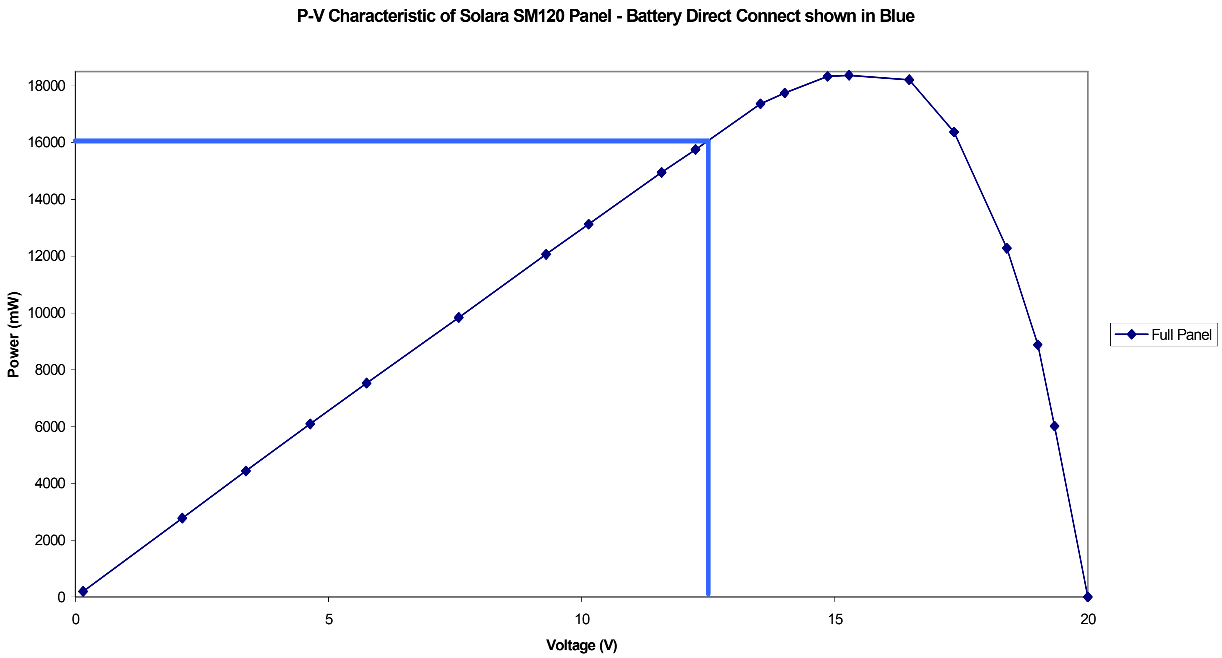

Figure 4. Power Delivery from a Panel Connected Directly to a Battery, an Unmatched Load.

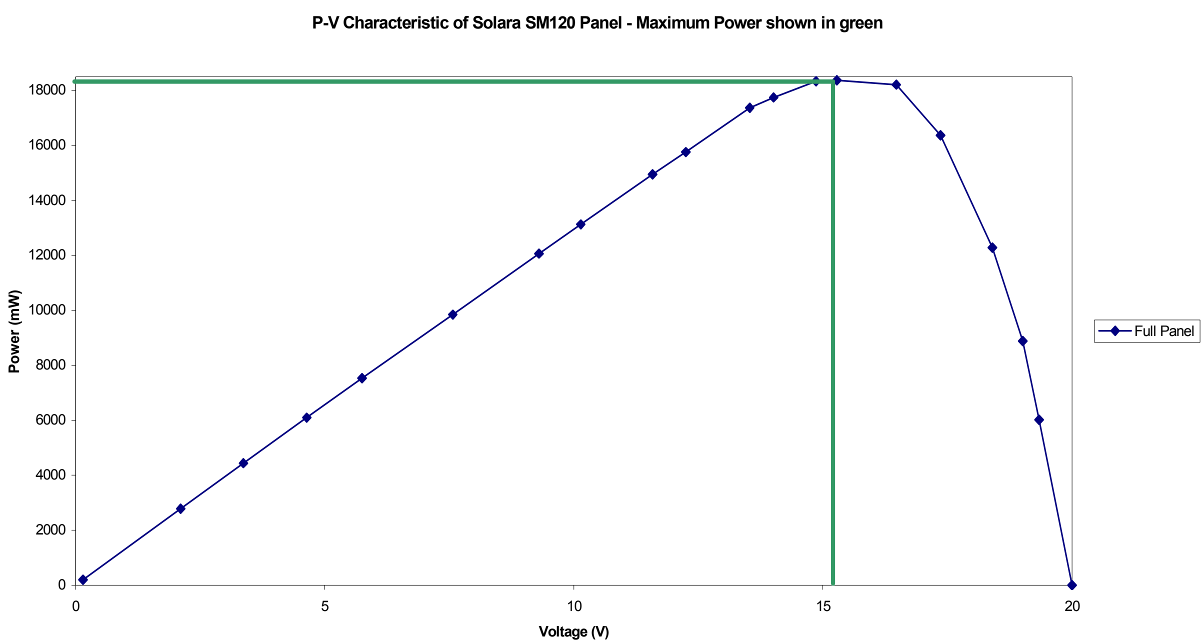

Figure 5. Power Delivery of a Panel Connected to a Matched Load.

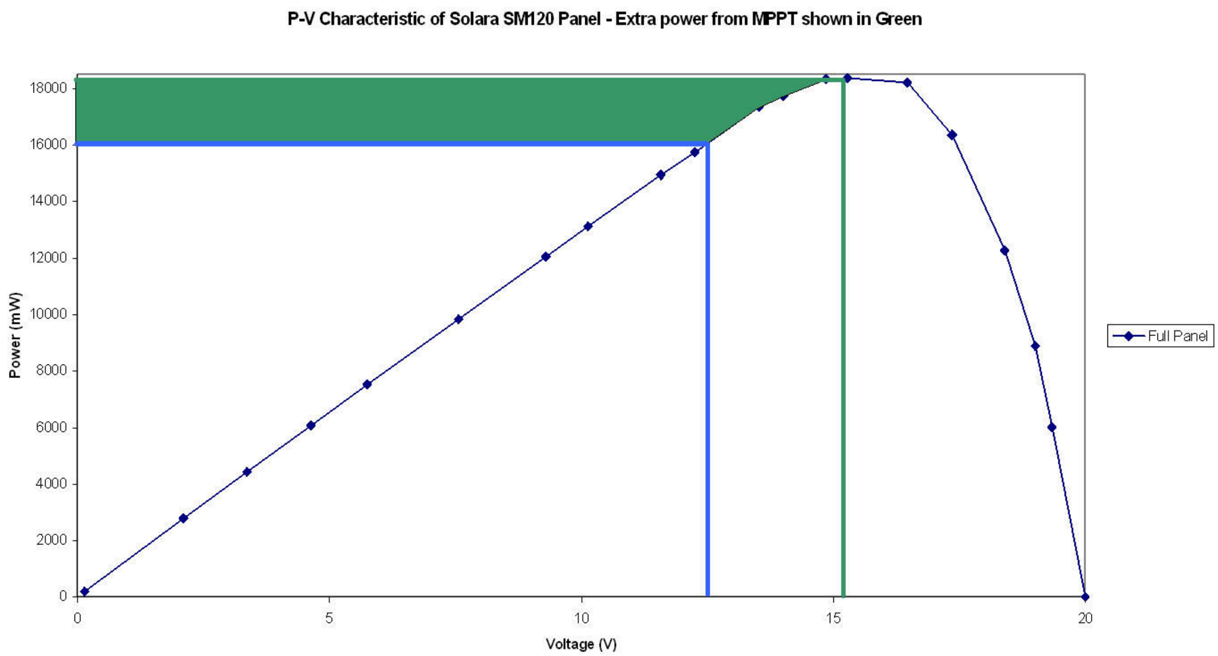

Figure 6. Additional Power Delivered with MPPT

TESTING CAPABILITIES IN DIFFERENT LOCATIONS VIA SOLAR SIMULATIONS

Solar simulations were performed in order to determine the operational impact of deploying a solar ERGL in different geographical locations. For each simulation, specific assumptions were made and the locations identified were used. NOAA historical data was used to populate the weather specifics for the simulation.

In Table 2 (results) we can see the impact on days of available autonomy and battery life at the different locations and for differing operating intensities.

Assumptions:

- Solar Engine: 20W 12vdc solar engine with a EMS.
- Photovoltaic (PV) or solar panel tilt is 60^{O} towards the south. The rule of thumb for panel tilt is the location's latitude plus 15^{O}.
- 60^{O} was chosen for these simulations.
- Two EPX 12volt batteries, 32 Amp/hrs. Temperature rating of -40^{O}C to $+60^{O}$C
- Operational Profile:
    - 24 Hours

- Daytime intensity simulated is 100, 69, and 33 candelas. Nighttime intensity is 30% of the daytime intensity. A special simulation was completed for Anchorage, Alaska for 10 Candela.
- Autonomy is greater or equal to the number of sunny days of a location.
- The rule of thumb for daily solar safety factor is 10%. That is to say everyday you should have at least 10% more solar power than actually needed.
- Battery life expectation is 3-5 years. Based on the manufacture recommendations that every 8.3^{O}C above 25^{O}C that a battery is in operation; the battery life expectancy is reduced by 50%.
- The EMS LED efficiency at different candela settings are given in Table 1.

- Locations:
  - Anchorage, Alaska 61 13'05" N 149 53'29" W
  - Chicago 41 50'60" N 87 39'00" W
  - Phoenix 33 26'54" N 122 04'24" W
  - Seattle 47 36'23" N 122 19'51" W
  - New York City 40 42'51" N 74 00'23" W
  - Guam (equatorial) 13 18'29" N 144 43'50 W
  - New Orleans 29 56'40" N 90 10'15" W
  - Moscow 55 45 00’00” N 37 37’00” E

Table 1.
EMS LED Efficiency.

Candela:	Efficiency:
100	70%
69	64%
33	60%

Table 2.
Results of Simulation of Operational Impact of Deploying a Solar ERGL in Different Geographical Locations.

Locations	Candela	Autonomy (No Sun Days)	Solar Safety Factor	Battery Life, years
	100	0 (21)	-0.62	10
Anchorage	69	0 (21)	-0.83	10
61 13'05" N	33	10.36 (21)	1.36	10
149 53'29" W	10	21.92 (21)	2.33	10
Chicago	100	6.62 (6.6)	1.46	6
41 50'60" N	69	9.45 (6.6)	1.98	6
87 39'00" W	33	17.39 (6.6)	3.36	6
Phoenix	100	12.4 (5.5)	2.63	2.1
33 26'54" N	69	17.4 (5.5)	3.6	2.1
122 04'24" W	33	31.23 (5.5)	6.3	2.1
Seattle	100	8.26 (8.1)	1.48	10
47 36'23" N	69	11.72 (8.1)	2.00	10
122 19'51" W	33	21.46 (8.1)	3.38	10
New York City	100	7.9 (8.7)	1.7	10
40 42'51" N	69	11.29 (8.7)	2.32	10
74 00'23" W	33	20.60 (8.7)	3.94	10
Guam (equatorial)	100	17.21 (8.7)	1.89	2.9
13 18'29" N	69	23.87 (8.7)	2.58	2.9
144 43'50 W	33	42.21 (8.7)	4.48	2.9
New Orleans	100	13.8 (8.28)	2.16	3.3
29 56'40" N	69	19.26 (8.28)	2.95	3.3
90 10'15" W	33	34.42 (8.28)	5.17	3.3
Moscow	100	4.07 (8.98)	1.25	10
55 45 00” N	69	5.98 (8.98)	1.69	10
37 37’00” E	33	11.41 (8.98)	2.82	10

TESTING OF GLASS COVERED 10W PANEL – ILLUMINANCE VS. VOLTAGE

Six 10W glass covered panels were tested to determine the voltage versus illuminance characteristics by measuring the ambient light illuminance with a Lux meter, and monitoring the panel voltage with a multi meter. One panel was found to be significantly different from the others, and was not considered in the analysis. The EMS detects night as less than 4.5 Volts, and day as greater than 6.0 Volts. By observing the illumination versus voltage for five panels and considering the time lag in measurement by the EMS, the night detection value for further consideration was found to be 55 +/- 30 Lux, and the day detection value found to be 90 +/- 30 Lux.

By using statistical process capability analysis techniques, mean and standard deviations for the sample data was calculated. Note that the sample size was not large enough to produce a statistically significant result, but the analysis was continued. The capability indices for both the day and night detection were found to 0.441 and 0.473, respectively.

To make the process capability indices greater than one, the specification center was adjusted to be closer to the mean value, and the tolerance revised. These new upper and lower specification limits imply that the specification will describe the day and night detection Lux levels in more than 99% of panels.

The recommended values for day and night detection when using 10W glass covered panels and the EMS two should be implemented in the engineering specifications of any product using this combination:

- Night is detected when the illuminance from ambient light falls below 65 +/- 45 Lux (USL 110 Lux, LSL 20 Lux).

- Day is detected when the illuminance from ambient light rises above 95 +/- 60 Lux (USL 155 Lux, LSL 35 Lux).

KEY PERFORMANCE VERIFICATION - TABLE OF KEY MANUFACTURER SPECIFICATIONS AND TEST RESULTS

Various tests were performed to verify the accuracy of determined specifications. The results of these tests are beyond the scope of this whitepaper however the results listed in Table 3 indicate the operational capabilities of a solar-powered LED ERGL.

ENVIRONMENTAL AND ECONOMIC BENEFITS ASSOCIATED WITH INTEGRATING SOLA-POWERED AND LED TECHNOLOGY SOLUTIONS WITHIN THE AVIATION INDUSTRY

Solar LED lighting systems operate with virtually zero energy costs for up to 25 years. With minimal scheduled maintenance in the form of battery replacement every four to five years, solar LED lighting systems are ideal for remote airports where maintenance and operating costs may be an economic or operator-based burden.

In addition, the reliability of solar LED lighting provides a safe alternative solution to commonplace electrical grid systems where lightning; faulty wiring, live circuits or water may become a risk to safety and human life. Inconsistent maintenance requirements, coupled with an unreliable power source place airports and surrounding aviation air traffic at unforeseen risks.

Table 3.
Overview of Performance Tests Conducted on Solar ERGL.

Parameter	Units	Min	Typical	Max	Validation	Compliant w/ Manufacturer Claimed Spec
Flashing Frequency	Flashes/ min	45	47	50	Internal Test Report –ERGL Flash Report	Yes
Intensity Settings	Candela	25 (8 night)	65 (19 night)	100 (30 night)	Internal test report - 8 inch LED Module	Yes
Night Transition	Lux	25	55	85	Internal test report - Glass Covered 10W Panel Illuminance vs. Voltage	Yes
Day Transition	Lux	50	80	110	Internal test report - Glass Covered 10W Panel Illuminance vs. Voltage	Yes
Wind Velocity	Miles/hr	n/a	n/a	300	Internal Test Report - ERGL Mount Stress Analysis Engineering Report	Yes
Temperature	°C	-40	20	+55	EMS Environmental Qualification	Yes

As a result of being completely self-contained and virtually maintenance free, solar LED airfield lighting solutions eliminate the need for costly infrastructures including cabling, regulators, transformers, trenching, conduit, vaults and power controls. Easy installation reduces the cost of contracted labor and outsourced engineering design. Overall, solar LED airfield lighting is a cost effective and practical solution for permanent, temporary, remote, or portable airfield lighting systems.

The relative capital cost of solar-powered lighting systems and wired systems vary according to local costs, however the Truckee Tahoe Airport in California installed a 500-light solar taxiway lighting system in 2004, and has reported that the system cost one-tenth that of a wired system. In addition, airfield management at Truckee Tahoe Airport estimated that installation of a hardwired system would have resulted in up to a year of air traffic disruption, including taxiway re-routing and runway closures creating substantial expenses. However, the cost-efficiency of their solar LED airfield lighting system extended beyond its installation. With its solar-powered LED lights, Truckee Tahoe is able to eliminate operating costs associated with hardwired lights and save more than US$16,000 per annum in energy bills.

Solar power is a clean, reliable form of renewable energy that showcases the latest in environmental stewardship and innovation. Solar power positively impacts air quality and by its unobtrusive infrastructure, leaves the lightest possible footprint on the environment. In fact, the US government's Energy Information Administration states that more than 25 percent of air pollution produced by burning fossil fuels is a by-product of electric power production [8]. Installing just one kilowatt (10 x 100 watt lights) of solar electric has the potential to reduce green house gas emissions over 25 years, by the following amounts:

- Carbon dioxide: 49,500 pounds
- Nitrous oxides: 125 pounds
- Sulfur dioxide: 400 pounds

Responsibility to the environment is one of the initiatives outlined in section 2.2 of the 2000 FAA National Aviation research Plan. Solar LED lighting and ERGL systems meet both safety and environmental objectives of the FAA, either as permanent or temporary solutions, or to augment other safety measures.

CONCLUSION

While runway safety is identified as one of the most important safety challenges facing the aviation community in the United States today, the solution does not need be complex. Fundamentally, runway incursions are the result of human error, but this is just one factor in a series of interactions enabling the events that set the stage for human error. To account for these errors, a number of safety systems are required, one of which involves adequate visual guidance systems that provide immediate warnings of probable collisions. Solar LED ERGL systems offer an economical and sustainable solution that addresses these ongoing safety challenges.

Though solar LED ERGL systems do not currently meet FAA standards, with growing public interest in solar technology, many believe it is only a matter of time. In the interim, as a temporary solution or an augment to safety, solar ERGL systems offer significant cost and operational advantages over traditional hard-wired technology, in addition to many environmental benefits. At minimum, a solar LED ERGL is significantly better than not implementing any safety precautions when cost or infrastructure is a concern. The issues are clear, the benefits are known, and the solutions are available.

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